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Survey of India.

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COLONEL J. R. HOBDAY, I.A.,

OFFG. SURVEYOR-GENERAL OF INDIA.

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CONTENTS.

AN ACCOUNT OF THE SCIENTIFIC WORK OF THE SURVEY OF INDIA, AND A COMPARISON OF ITS PROGRESS WITH THAT OF FOREIGN SURVEYS,

BY LIEUT.-COLONEL S. G. BURRARD, R.E., F.R.S.,

SUPERINTENDENT OF TRIGONOMETRICAL SURVEYS.

The scientific work of the Survey of India consists of—

Principal Triangulation
Levelling Operations
Astronomical Operations
Pendulum Operations
Tidal Operations
Magnetic Survey
Solar Photography.

I beg that I may show in a few brief notes the uses and aims of the scientific work of the survey, but before doing so I wish to premise that no distinction can properly be drawn between scientific and practical work. Many operations conducted on scientific principles have immediate practical uses: they may in fact be likened to the exploitation of visible outcrops of coal. Others are more experimental, and may be likened to borings for invisible coal, believed to exist at certain depths. Others again are speculative, and may be likened to deeper borings, made to ascertain the strata in the crust, with the hope, that something valuable, perhaps coal or iron or gold, may turn up. But whether such operations are practical or experimental or speculative, they all have the same twofold purpose, *viz.*, the acquisition of information, and the rendering of that information useful. Almost all the scientific operations of the Survey of India will be found to fall into the first category, and to possess immediate practical uses.

Before I enter into the details of the different scientific operations of the Survey of India I may perhaps be allowed to refer briefly to the general question of the connection between science and surveys in modern times.

The primary object of a national survey is the making of maps, and all operations are subordinated to that end. It is for topographical purposes that a national survey measures its allotted portion of the earth's surface. If, however, these measurements be subsequently combined with astronomical determinations, the size and shape of the earth can be deduced, and a knowledge of this size and shape is essential to astronomers, geographers, geologists and meteorologists, all of whom look to surveys for information.

The great accuracy of modern astronomical observations for stellar and lunar parallax, and the difficulty which mathematicians still experience in predicting exactly the places of the moon and the planets, are constantly necessitating more refined determinations of the figure of the earth, and astronomy is continually bringing pressure to bear upon surveys to lend her their aid—for her celestial measurements must always emanate from a terrestrial base.

Man's first conception of the earth's figure was a plane: Greek philosophers thought it a sphere: Sir Isaac Newton showêd that it must be a spheroid. Colonel Clarke, of the Ordnance

Survey, contended that it was a triaxial ellipsoid. Modern Geodesy, after encountering great difficulties in testing in the field the theories of Newton and Clarke, has pronounced it a geoid. Astronomy now wishes us to tell her the dimensions of this geoid, and its departures from a spheroid.*

In the days of Everest the figure of the earth was deduced from linear measurements, and the Great Arc of India was the only series of triangulation in India originally designed for a figural determination: all our other triangulation was intended and executed for the purpose of controlling topography. In 1858, Colonel Clarke showed that the figure and dimensions of the earth could be better deduced from measured areas than from measured arcs, and the whole triangulation of India became at once available for the discussion, provided it were subjected to astronomical tests.

A small portion only, however, of the earth's surface has so far been surveyed; and our present idea of the dimensions of our planet has been derived from wide generalisations. The total area of land and sea amounts to nearly 200 millions of square miles: the areas that have been surveyed do not aggregate 6 millions of square miles.

The determination of the figure, and of the dimensions and of the specific gravity of the geoid is now in the hands of an International Geodetic Association, at whose conferences Professor George Darwin, F. R. S., represents Great Britain: India's co-operation is the more valued by the Association, because she alone of the civilized nations possesses an equatorial area, and because she includes within her dominions the highest points of the earth's surface.

The amount of money spent annually by Europe and America on astronomical observations, runs into many millions sterling: humanity is striving to discover new facts concerning the myriads of distant bodies moving in space. As her development progresses, she grows ever more desirous too of investigating the one celestial body, which she can touch, and on which she finds herself travelling amongst the stars.

The difficulties, however, of studying even our own earth are great, because we are tied to its surface: our meteorologists cannot ascend into the atmosphere; our geologists cannot penetrate into the interior. We have learnt that the globe of rock, which constitutes our inter-planetary home, is the source of two great forces, gravity and magnetism; and a knowledge of the actions of these forces has become of importance to almost every branch of science. Their actions we have discovered are strangely dissimilar, and vary both with time and place.

The civilized nations are now making gravimetric and magnetic surveys of the earth, and are measuring the intensities, the directions and the pulsations of the terrestrial forces. India has been asked to bear her share, and to carry these operations over her own fraction of land-surface.

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* The geoid is the figure enclosed by the surface of the sea: this surface is that of a spheroid disfigured by protuberances and hollows.

THE PRINCIPAL TRIANGULATION OF INDIA.

Its Accuracy.

The principal triangulation of India has been repeatedly attacked on the grounds that it is too accurate and too scientific for practical purposes. In 1800, in 1824, in 1850 and in 1886, attacks were made, but the Government after enquiry ordered its continuance. The present seems a good opportunity to take stock, to see what the triangulation has done for us and what it has cost us, and to consider by the light of modern requirements its accuracy and its errors.

The operations of a survey may be conveniently divided into, (1) the controlling framework, (2) the artistic superstructure. In discussing errors and accuracy it is advisable to keep these two divisions distinct, for whilst the controlling framework has to be guarded against cumulative errors, the artistic superstructure is only liable to accidental or local errors. The framework is constructed as follows :—

Foundation	Principal Triangulation.
Plinth	Secondary Triangulation.
Walls	Tertiary Triangulation and Traversing.

Points fixed by tertiary triangulation or traverse should be sufficiently numerous to save the topographer from cumulative errors. Tertiary triangulation and traverses themselves are liable only to accumulate errors over the short distances between secondary stations. In secondary triangulation the accumulation of error is confined to the distance which separates stations of the principal triangulation. In all survey operations, therefore, *after* the principal triangulation the accumulation of error is arrested : but what arrests the accumulation of error in the principal triangulation itself? The answer is that observations of a principal triangulation must be sufficiently accurate in themselves to avoid *embarrassing accumulations of error.*

We have been accustomed to state the error of triangulation in so many inches or so many feet per mile, and this custom has led laymen to believe, that the errors of principal triangulation are dispersed throughout its length. But the statement that an error has been found of 1 foot in a mile, is merely made to enable the merit of the triangulation to be gauged : in a length of 500 miles an error generated of a foot a mile is not dispersed, but is accumulated at the terminal. It follows, therefore, that the *requisite* precision of a principal triangulation must vary with the *distance* to be triangulated.*

The following table shows the relative degrees of accuracy in the triangulations of different countries : the precision and length of the triangulation of Great Britain have been taken as the units :—.

Country.	Precision of triangulation.†	Length of triangulation.	Ratio of precision to length.
Russia	2·0	3·3	0·6
India	2·2	3·0	0·7
Great Britain	1·0	1·0	1·0
Austria	2·0	1·4	1·4
Italy	2·0	1·25	1·6
Spain	2·2	1·2	1·8
France (modern)	3·0	1·2	2·5
Prussia (modern)	3·6	1·4	2·6

* The *weight* of triangulation varies inversely with its distance. The error of mean square increases with $\sqrt{\text{distance}}$, but in practice the terminal accumulation over a great length appears to be generally more due to systematic than to accidental errors.

† General Ferrero's report to the International Conference at Stuttgart in 1898.

The triangulations of South Africa and the United States are equal in precision to those of France and Prussia.

So long as a country is isolated, its survey will not concern itself with errors accumulated at its frontiers: a country like Prussia, whose triangulation meets other triangulations on all sides, has experienced troubles that India has never felt. But India is losing her insularity, and though the loss may be slow it is certain. Fifteen years ago the Indian frontier topographers began to experience embarrassments, because the longitudes of Indian mapping were 2½ miles in error. It was futile to tell them that an error of 2½ miles in 6,000 miles was a small matter; the error was not dispersed over the 6,000 miles between Greenwich and India: it came in between our Indian and Afghan topography. The frontier surveyors suggested that each meridian should be drawn in two places on all Indian maps, and they subsequently proposed to project trans-frontier maps in terms of Europe instead of in terms of India, thus transferring the 2½-mile gap from their front to their rear. It was the topographical surveyor and not the scientific branch that was experiencing the trouble. The incident teaches that an error of 2½ miles may remain unnoticed during a century of insularity, but that at the first appearance of a small scale trans-frontier survey it begins to cause embarrassment.

The accuracy of European surveys gradually increased throughout the nineteenth century, and the difficulties of adjusting the discrepancies between contiguous triangulations became ever correspondingly greater. Eventually it was agreed to create a permanent court of arbitration, and the International Geodetic Association, to which all civilised nations now belong, was called into being.

Its Errors.

The triangulation of India has been controlled by base-lines: its errors of length do not, therefore, need consideration.* But base-lines exercise no control on direction, and if our astronomical results are to be believed, the triangulation has exhibited a constant tendency to deviate from the true course. Between Karachi and Calcutta an error in azimuth of 11″ has been generated, and this has increased to 15″ at Mandalay: our trigonometrical points in Eastern Burma have consequently been all displaced some 400 feet too far south. Between Cape Comorin and Peshawar an azimuthal error of 12″ has been generated, and the relative orientation of these two places is 200 feet in error in consequence.

But the chief errors in the framework of Indian mapping are due not to faults in its construction, but to its location on the globe. Owing to errors in the original observations of longitude the Indian area has been placed on the globe 2½ miles too far east: owing to obstacles placed by nature in the way of correct determinations of latitude in Central India, the Indian area has been located some 600 feet too far north on the globe.

Owing mainly to the deformation of the geoid in India, Everest's figure of the earth, on which all our calculations of latitudes and longitudes are based, has been given a diameter too small by 2 miles; the result is that our maps, though correct in their detail, have all been given too large a share of the earth's surface: our distance from Peshawar to Cape Comorin has been accurately measured, but we have given it in our maps 11 seconds more of latitude than it has a right to: our distance from Karachi to Mandalay has been made to embrace 17 seconds more of longitude than it is entitled to. At present we have no neighbours complaining of these overlaps, and the time has not come for us to trouble about them: it would in fact be premature for us to adopt a new figure, when great earth measurements are now in progress in Africa and America, and it would be premature for us to attempt a new location of India on that figure until our pendulum and astronomical work has been extended.

* In the 747 miles separating Karachi and Attock the error in *length* accumulated in the triangulation, and eliminated by the measurement of the Attock Base-line, was 99 feet.

If we sum up the errors in position accumulated on our frontiers, they are as follows:—

Peshawar has been placed too far north in latitude by 400 feet owing to figural errors, and by 600 feet more owing to errors of location on the globe: it is thus shown on our maps 1,000 feet too far north. Peshawar is, moreover, shown 2½ miles too far east of Greenwich.

The Salween has been placed in longitude 1,100 feet too far east owing to figural errors, and 2½ miles too far east owing to errors of initial longitude: it is thus shown on our maps 2¾ miles too far east. The Salween is shown some 300 feet too far north, the effects of the initial latitudinal error and of the accumulated azimuthal error being opposite in East Burma.

It is difficult to define numerically the meaning of an "embarrassing accumulation of error," because as a survey matures it begins to feel the pinch of errors, which it failed to notice in its youth. Any accumulation of error is embarrassing that obliges surveyors to recalculate their data. Changes in data due to revisions of computations, even when such revisions are based upon important new observations, cause great inconvenience and decrease the value of the data for co-ordination purposes.

In dealing with problems connected with the determination of the figure of the earth no inconvenience arises from using revised data, and it is relatively easy to make revisions, as comparatively few points are concerned.

When triangulation is being used for controlling maps and co-ordinating surveys, the aim of adjustment is to avoid purely local distortions; but when it is being employed to investigate the form of the geoid, it is of importance only to have correct relations between very distant points. In discussing, then, the meaning of "embarrassing accumulations of error," we have only to consider the geographic purposes of triangulation, and we can dismiss from our minds the geodetic.

There is no doubt that the error of 2½ miles in longitude has already become embarrassing to India: our $\frac{1}{1,000,000}$ maps have different longitudes to our 1-mile maps, and our 4-mile maps have longitudes differing from the other two, and these discrepancies must be inconvenient to the great body of map-users, who are not in the secret of the longitude footnotes. The longitude error is in fact so large that it will probably, in the future, necessitate a revision of data: and if such a revision comes to be carried out, the opportunity will doubtless be taken to eliminate also our figural and latitudinal and azimuthal errors.

As to the error of 1,000 feet in the latitude of the triangulation at Peshawar, this accumulation causes at present no inconvenience: but if our triangulation ever comes to be connected with Russia's, the overlap in latitude will amount to half a mile or more, because Russia is projecting her triangulation on too small a spheroid, just as we are doing. The two surveys will then have different values of latitude for every boundary pillar; it is impossible to foresee now what course they will agree to take: but if we may judge from examples in Europe, they will refer to the International Association, and they will perhaps be advised to correct their data.

Its cost.

In a Parliamentary paper published in 1851, Sir A. Waugh estimated the cost of the principal triangulation at Rupees 7-2-5 per square mile. If the same work were to be executed now, it would probably cost double. Since the estimate was prepared, triangulation has been carried over Rájputána, Sind and the Punjab, at a cost averaging 15 Rupees per square mile. The average original cost of the whole principal triangulation of India may be estimated to have

been about 9 Rupees per square mile. This cost applies to the area actually triangulated, and not to the total area controlled.

In 1798 Colonel Lambton started working on the network system, but in 1824 Colonel Blacker and Colonel Everest substituted the gridiron system and, by so doing, greatly reduced the cost. The whole area of India is almost three times as large as the area triangulated, and as the whole has been controlled by principal fixings, the cost of the triangulation works out at about 3 Rupees per square mile. The cost of a 1-inch = 1 mile survey exceeds generally Rupees 20 per square mile, and amounts at times to Rupees 40 or more. The secondary and tertiary triangulation on which a 1-inch survey is based, will cost 10 Rupees per square mile: the traversing on which a 1-inch survey is based in flat countries will cost 15 Rupees per square mile. The principal triangulation will, therefore, increase the original cost of a 1-inch survey by less than 10 per cent.—by less perhaps than the cost of its fair-mapping.

But a 1-inch survey requires to be periodically revised, and the principal triangulation remains available for all revisions. Moreover, surveys on larger scales than 1-inch are in progress throughout the country at costs varying from Rupees 60 to Rupees 200 per square mile, and these are all based on the same principal triangulation. Furthermore, it must be remembered that the true expense of our principal triangulation has not been its total additional cost, but its excess over the cost of the secondary triangulation, which would have had to be substituted if it had not been executed.

The differences between our principal and good secondary triangulations have been as follows :—

(*a*) The principal costs perhaps 20 per cent. more than the secondary.*

(*b*) The principal stations are more solidly built, and the positions of the mark-stones are carefully protected for the use of the future.

(*c*) Our principal triangulation has generated an error in position of 200 feet and in azimuth of 12″ between Cape Comorin and Peshawar: our good and expensive secondary work such as the Quetta series, might easily have generated over the same distance an error in position of half a mile and in azimuth of 150″. Triangulation such as the Kalat series might well have generated between Cape Comorin and Peshawar an error in position of a mile and a quarter, and in azimuth of 400″. Secondary work, such as that observed with a 12-inch theodolite on the Cutch Coast, might have generated an error of 5 miles in position and of 20 minutes in azimuth.

Its uses.

It is a great mistake to imagine that the principal triangulation of India was executed for the purpose of measuring the figure of the earth. ***The principal triangulation of India was executed to control the topography.*** A triangulation, however, furnishes only the distances apart of the points fixed and their mutual directions: these data are not sufficient for topography, which requires the latitudes and longitudes of points. In order to convert the distances and directions of the triangulation into the latitudes and longitudes of topography, we require a knowledge of the earth's dimensions. When Lambton commenced the triangulation of India, the figure of the earth was not known with sufficient accuracy even for the calculation of the spherical excesses of his triangles. During his twenty-five years of trigonometrical work he was always, as he extended his triangulation, having to recalculate the earth's figure, and

* Secondary is cheaper than principal in that its progress is faster, but dearer in that its triangles are smaller. In clear weather and suitable country the extra size of the principal triangles will at times compensate the slowness of progress, and render the principal on the whole cheaper than secondary.

he died without having succeeded in obtaining a satisfactory result. In 1823 Everest attacked the problem, and in the belief that Lambton's arcs had been too short, he extended the triangulation northwards into Central India. To his great disappointment a careful determination then gave the polar diameter of the earth longer than the equatorial. Though this anomaly had been met with in other countries, Everest was convinced that the fault lay in his measurements and not in the theory of gravitation.

It was not till 1830 that Everest succeeded in obtaining a figure of the earth sufficiently accurate for the needs of topographers.

There is no doubt that Lambton's and Everest's unexpected difficulties attracted much attention in Europe: these officers were testing in the field the great Newtonian theory that the earth was an oblate spheroid, and their instructive failures took the scientific world by surprise. But the interest excited in their work does not alter the facts that the principal triangulation was executed for the control of topography, and that its utilisation for figural determinations was incidental.

The *first* great practical use of the principal triangulation has been its prevention of embarrassing accumulations of errors at our frontiers.

Its *second* use has been to unify and co-ordinate all the separate surveys of Madras, Bombay Sind and Bengal; to give them one origin; to combine them into one harmonious whole: to get rid of gaps and overlaps from the internal mapping of India; to free India from the internal boundary disputes that have so troubled other countries.

Its *third* use has been to facilitate and cheapen by tower stations the topographical surveys of the extensive plains of Upper India, a difficult country to map, being the only large portion of the earth's surface that is flat, intricate and valuable.

Its *fourth* use has been to enable the positions and heights of distant peaks to be determined with accuracy all along our trans-frontier, and thereby to afford points to topographers in Afghanistan and Tibet.

Its *fifth* use has been to furnish perpetual points for the use of posterity, without which revisions of maps would be impossible.

Its future.

The questions that arise concerning the future of the principal triangulation have to do, firstly, with the preservation of its stations, and secondly, with its extensions.

The measures that have been taken to preserve the stations have not been altogether successful, and require, I think, to be supplemented—but not supplanted—by departmental inspections: furthermore, seeing the importance of preserving all these marks intact I think that a call by the Government of India for a special report on the condition of all existing stations, if made every twenty years, would tend to prevent the protective work from degenerating into routine.

The only future extensions of triangulation that require present consideration are those of Burma and Baluchistan. In Burma the completion of the Great Salween series, the extension of the Mandalay Meridional series to Sadiya, and the revision of the Assam Valley triangles are required to consolidate the triangulation east of Chittagong and Gauhati.

A principal series is being carried westwards from Kalat in order to co-ordinate the separate surveys that have been made of recent years in Baluchistan, and to provide a foundation for other surveys that are likely to be required in those regions in the near future.

If we are to follow the practices of European nations, of the United States, and of South Africa, we should arrange to measure two or three base-lines in Burma, and possibly one in Baluchistan, within the next few years.

The following table shows the numbers of base-lines of the first class, measured in various countries :—

	No. of Base-Lines.*	Area triangulated, in thousands of square miles.	Ratio of Base-Lines to area.
Italy	9	110	$\frac{1}{12}$
Germany	13	204	$\frac{1}{16}$
Great Britain	6	121	$\frac{1}{20}$
France	7	207	$\frac{1}{30}$
Russia	19	2,000	$\frac{1}{105}$
India	10	1,520	$\frac{1}{152}$
Burma	0	240	0

There is a base-line at Mergui, in South Burma, but its length of 3 miles is too small to allow of its being classified as first class. The base-lines in India Proper are completed and though it is a matter of regret that the projected base-line at Bombay was omitted, the question is closed: whether our distant successor will re-open it will depend upon the future developments of geodesy.

In the above list there is little doubt that the 2,000,000 square miles allotted to Russia are in excess of her triangulated area: prior to 1895 good triangulation had been carried over Western and Southern Russia, Finland, the Caucasus and the Cis-Caspian Provinces: and a great arc of parallel had been taken eastwards from Warsaw to Orenburg, and was being extended into Central Asia.

* General Ferrero's report to the International Conference at Stuttgart in 1898.

THE LEVELLING OPERATIONS.

Their uses.

Levelling operations conducted on scientific principles form as essential a part of a survey as triangulation. Levelling constitutes the framework that controls the vertical measurements of a survey, just as triangulation controls the horizontal measurements. In addition to affording a basis for topographical heights, levelling contributes to topography by co-ordinating the Canal and Railway levels and rendering them available for maps.

Errors of vertical angles.

The altitudes entered on Indian topographical maps have been mostly derived from vertical angles: the degree of accuracy with which these angles have been measured has varied from those observed to decimals of a second with large telescopes to those observed to the nearest degree with wooden clinometers. Our levelling operations have brought to light the following errors in the first class heights of the principal triangulation:—

Madras Coast	5 feet too high
Bombay Coast	17 " " "
Mysore	9 " " "
Deccan	7 " " "
Cutch Coast	11 " " "
Khândesh	14 " " "
Punjab	5 " " "
Ganges Valley	errors varying from 13 " " " to 31 feet too low.

Errors of height amounting to 20 and 30 feet are of but little importance in mountainous regions, but are liable to mislead engineers who have to study the hydrography of the plains.

To take a well-known example—Ambala is in the Indo-Sutlej basin and its height is 902 feet: Sahâranpore is in the Gangetic basin and its height is 903 feet. From Ambala to Sahâranpore the ground rises 11 feet in the first 20 miles; the natural watershed between the drainage systems of the Arabian Sea and the Bay of Bengal is 913 feet high near Mustafabad railway station: the ground then falls 7 feet in the 13 miles to the Jumna, and 3 feet in the 17 miles between the Jumna and Sahâranpore.

Work in hand.

The work in hand at present in connection with Levelling may be classed as follows:—

(1) Erection of standard bench-marks.

(2) Extensions of lines of levelling in the field.

(3) Preparation of level charts.

(4) Preparation for press of half a century's levelling results.

The scheme of erecting standard bench-marks has been initiated this winter. From information received at different times there are reasons to fear that numbers of ordinary bench-marks are destroyed when towns expand, and when railways or roads are widened. In the last few years we have discovered that the bench-marks between Rangoon and Mandalay have not maintained their original altitudes: the discovery was accidental; we had not intended to revise the Burmese levels. Revisions in India might bring to light similar displacements

We now propose to erect standard bench-marks in the important towns of India: these new marks will be solidly built in carefully chosen places, and will be handed over to the local engineers, who will report to the Survey annually: their heights will be determined by levelling and engraved on the stones.

Projected extensions.

The lines of levelling that remain to be executed may be divided into three classes:

(i). The scientific, which are required to close circuits and to furnish the closing errors for the forthcoming adjustment of the level net. These amount to 6 years' work.

(ii). The engineering, which are required by the Public Works Department to control and unify their Canal and Railway levels. These amount to 17 years' work.

(iii). The protective, which are required to fix the heights of our standard bench-marks and to preserve thereby, for posterity, a few of the altitudes determined in our time. These amount to 20 years' work.

Of these three classes the third is of supreme importance; to postpone, however, the lines of levels required by the Public Works Department for 20 years, is practically to omit them altogether.

For many years past the levelling detachment has been assisting the Public Works Department, and has furnished bench-marks to the Bengal State Railways, to the Burma Railways, to the Burma Irrigation Department, and to the Irrigation Department of Sind. There has been no opportunity of completing the scientific lines, which are wanted to consolidate the network.

The preparation of Level Charts was commenced thirty-eight years ago: 34 Charts have been published, and 112 remain. Level Charts are intended to show all Canal and Railway levels in terms of the datum of the Survey, and will be of use to both engineers and topographers.

Comparison with Foreign Surveys.

I have endeavoured to ascertain the amount of levelling executed in Europe and America, but it is difficult to obtain statistics: in all countries the publication of results lags behind the fieldwork.

India: Up to May 1904, there had been executed in India 15,500 miles of precise levelling.

Great Britain: Prior to 1861, the Ordnance Survey had executed 4,000 miles of accurate levelling in England and Wales, 3,000 miles in Scotland and 1,500 miles in Ireland. These operations have been widely extended since 1861.

France: Prior to 1898, France had carried out (*a*) 7,000 miles of levelling of the highest degree of accuracy, (*b*) 10,500 miles of a class of levelling, denominated by her surveyors second class, (*c*) 4,900 miles of so-called third class, (*d*) 10,200 miles of so-called fourth class. The lower orders of levelling are used in France to break up the fundamental network into smaller areas.*

United States: In 1899, the Survey adjusted their precise level net; 19,753 miles of precise levelling were included in the net: between 1899 and 1903, additional first class levelling extending over 6,000 miles was carried out.*

Germany: Prior to 1892, Germany had carried out 18,600 miles of first class levelling, and Austria had carried out 10,000.*

Japan: Prior to 1898, Japan had carried out and projected 5,700 miles of levelling of precision.*

* Reports of the International Conferences, Stuttgart 1898, Paris 1900, Copenhagen 1902.

Ratio of first class Levelling to area :—

Germany in 1892	$\frac{1}{11}$
Great Britain in 1861	$\frac{1}{14}$
Austria in 1892	$\frac{1}{21}$
Japan in 1898	$\frac{1}{22}$
France in 1898	$\frac{1}{28}$
India in 1905	$\frac{1}{110}$
United States in 1899	$\frac{1}{116}$

Seeing how valueless large portions of the Indian area are, no one could advocate that the ratio for India should be raised to that of Great Britain. American surveyors would probably take exception to the ratio allotted to their country, as it makes no allowance for the large unsurveyed regions that form part of the United States.

In adjusting the errors of her levelling net, France had to take into account that her lines had been connected with those of foreign countries at 18 different points, *viz.*:—

with Spain at three points,
with Italy at three points,
with Switzerland at five points,
with Germany at three points,
with Belgium at four points.

Owing to the errors in her connections with France, Switzerland had to revise 80 miles of levelling in 1896 and 183 miles in 1897. India's insularity renders her levelling independent of foreign checks.

Their Cost.

Seeing how useful our levelled heights and bench-marks have been in India to the engineering departments, it is questionable whether we ought to charge the total expenditure on them against topography. If, however, we decide to do so, the cost to topography of the levelling control, up to the present time, will work out at about nine annas per square mile of area controlled.

On the average four bench-marks have been erected in every 1-inch standard sheet of surveyed area.

THE ASTRONOMICAL OPERATIONS.

Primary aims.

The primary duty of the Astronomical party is the location of India in its correct position on the globe. The origin of our triangulation is a point in Central India: we have had to determine astronomically the terrestrial position of this point, and we have had to determine astronomically the terrestrial directions in which our several diverging series of triangulation have trended; one series has run into Makrân, others into the Punjab and Himalayas, others into Assam and Burma, others into South India, and, in spite of unremitting care, all these ramifications have developed errors of orientation and direction.

The area of India is more than one-fourth of the total triangulated area of the world: it is the largest triangulated area that has yet been undertaken by one survey; it is the largest triangulated area that has ever been made to emanate from a single point: and our astronomical officers have had to fit this area into its true position on the globe. They have had to discover the relative dimensions of the area to be located and of the globe receiving it: they have had to keep a watch on the triangulation, to see that it is not trespassing beyond our correct frontiers and coasts, and to warn us of the errors that we shall have to deal with when we meet with a foreign survey.

It must be remembered that nature has placed obstacles in the path of astronomical surveyors in India: the direction of gravity is the only test they have of verticality, the surface of liquid at rest is their only test of horizontality, and in no other part of the world has the direction of gravity been found to undergo such abnormal variations as have been discovered by the Russians in Fergana and by ourselves in Northern India: in no other country does the surface of liquid at rest deviate so much from the horizontal.

There appears to be an idea that the primary object of our astronomical work is the investigation of mountain attraction, and of deflections of the plumb-line. But this is a mistake. Its true goal is the determination of the geographic errors of area, shape and position that have been generated by the triangulation. But just as the triangulators found themselves unable to control the topography without a knowledge of the figure of the earth, so have the astronomers found themselves unable to control the triangulation without a knowledge of the direction of gravity. Just as the triangulators had to digress, and make earth-measurements, so have the astronomers had to halt on their way to investigate the attractive effects of mountains.

It is true that discoveries made in the course of these secondary operations have won the interest and sympathy of learned societies in Europe: the discovery that an extraordinary deficiency of matter underlies the Himalayas, that a range of mountains is hidden and buried beneath the plains of Central India, that seaward deflections of gravity prevail round the coasts of southern India—these discoveries have led geologists and geodesists to press for a further investigation of the distribution of mass in the earth's crust. But the interest that has been awakened does not alter the fact that the primary object of our astronomical operations is geographic.

The heights of Himalayan peaks.

Difficult questions have arisen in connection with the heights of the Himalayan and trans-frontier peaks: our values for these heights are in error, (*1stly*) because of the extraordinary deformation of the level surface at the observing stations in submontane regions; (*2ndly*) because of our ignorance of the laws of refraction, when rays traverse rarefied air in snow-covered

regions; (*3rdly*) because of our ignorance of the variations in the actual heights of peaks due to the increase and decrease of snow. It is part now of the programme of the Astronomical party to determine the errors in height arising from geoidal deformations, to investigate the laws of refraction at high altitudes, and to measure the actual variations that are occurring in the heights of peaks.

There are but three known methods of determining the height of a station, *viz.*, (1) by Spirit level: (2) by Atmospheric pressure: (3) by Angular measurement. Of these three methods the first two require the station itself to be visited, and the third alone is available when the station is inaccessible.

To obtain an idea of the degree of uncertainty which attaches to values of heights determined from very distant observing stations, we may suppose that an observer measured the elevation of Mount Everest from Darjeeling in October, and again from the plains of Bengal in April; his second series of observations might give a larger value of height than his first series by 100 feet on account of geoidal deformation, by 300 feet on account of inequalities in refraction,* and by 100 feet or more on account of increase of snow—by 500 feet in all.

I do not presume to argue that our heights are in error by this amount, but I do say that the above figures give a fair numerical idea of the range of uncertainty. Apart from topographical requirements, it is of interest to the world at large to know the heights of the highest points of the earth, and the duty of determining them belongs to the Indian Survey.

The values of height now attaching to the three highest mountains in the world are by no means the most probable.

Heights of the three highest mountains in the world.

	Present Survey values of height.	Most probable values.
Mount Everest	29,002	29,141
K²	28,250	28,191
Kinchinjunga	28,146	28,225

It is possible that we are robbing Kinchinjunga of the honor of second place.

My most probable values of height have been derived from observations of refraction that were not available when the present Survey values of height were adopted. It would, however, be premature to exchange yet our present values for the most probable values, for nothing leads more to confusion than repeated alterations of data.

It is true that the values at present most probably would be improvements on the accepted values, but we want something more than improvement or correction to justify us in changing data: we want finality and certainty, and these we shall never attain until we appreciate the magnitude of the problem, and go systematically to work. In the course of the Trigonometrical Survey we have accumulated a mass of evidence relating to refraction, but it is entangled with the effects of local attraction and of snowfall, and it cannot be classified or utilised, until we have disentangled the three.

Special duties in the past.

The Astronomical party of the Survey has been often called upon in the past to perform miscellaneous duties that would in Great Britain have fallen upon the staff of Greenwich Observatory. It has had to observe Transits of Venus: in 1894, 1895 and 1896 it was observing in Persia and Europe to determine the error of Indian longitudes: in 1898 it was deputed to assist

* Refraction is probably less at Darjeeling than over the plains: if, therefore, the same co-efficient be employed, the height obtained from Darjeeling will be less than that obtained from the plains.

the Astronomer Royal in observations of the total Eclipse of the Sun. It has worked in conjunction with the Government Astronomer at Madras to obtain a fundamental value of latitude for the Indian Star Catalogue.

Special future work.

The Director of Kŏdaikánal Observatory requested the Survey some years ago to determine his geographical co-ordinates both astronomically and by triangulation : I regard this request as of first importance, but no officers have been available for the work.

It is to be hoped that in the future the Astronomical party may be given an opportunity of determining the mean density of the earth: Astronomers Royal did this for Great Britain at Schiehallion and Cardiff, and the Ordnance Survey made a fine determination at Arthur's Seat at Edinburgh. The three measures were, however, not accordant*, and a determination in the low latitudes of India would be a valuable contribution. The present time is peculiarly opportune, because we could count upon the co-operation of our pendulum party: in no one of the British determinations could astronomical and pendulum observations be combined. When, therefore, the Ordnance Survey had to deduce the weight of the earth from the weight of Arthur's Seat, they were not aware of the density of the crust underlying Arthur's Seat, and they were obliged to assume that it was normal: if we undertook to measure now the relative weights of the earth and Mount Abu, we could, with our pendulums, discover whether the foundations of Mount Abu were abnormally heavy or light.

Comparison with Foreign Surveys.

The errors in the geographic position and area and shape of a survey are determined by Astronomical measurements of latitude, longitude and azimuth at stations of its triangulation. The following table shows the present position of the Survey of India as compared with other surveys: —

Survey of	The proportional number of stations of the triangulation at which Astronomical observations have been made.†		The total number of Arcs of longitude measured.‡
	For Latitude.	For Azimuth.	
Germany	1 in 3	1 in 4	197
Trans-continental triangulation of America	1 in 2	1 in 3	67
Great Britain	1 in 7	1 in 4	‡
Austria	1 in 6	1 in 7	95
France	1 in 8	1 in 11	62
Italy	1 in 11	1 in 12	34
Russia	1 in 12	1 in 12	81
India proper	1 in 11	1 in 12	47
Baluchistan	0	0	2
Burma¶	0	1 in 11	5
Kashmir	0	0	0

* Mr. Maskelyne at Schiehallion . . . 4·56
Sir George Airy at Cardiff . . . . 6·57
Sir Henry James at Edinburgh . . . 5·32

† Reports of the International Conferences at Stuttgart, 1899, and at Copenhagen, 1903.

‡ Many of the arcs of longitude measured by Great Britain, cross the English Channel and the Atlantic: it is doubtful whether these should be included in the table.

¶ Including the Manipur Meridional series.

Normal future work.

Observations for latitude are still much wanted on branches of our triangulation, more especially in Burma, Baluchistan, Kashmir and the Himalayas.

Observations for azimuth will be required on future extensions of the triangulation.

The measurement of a few additional arcs of longitude in Burma, the Punjab, South India and Kashmir has for many years been considered desirable.

International determination of the variation of latitude.

Of recent years endeavours have been made in Europe and America to measure the changes in the positions of the earth's centre of gravity and of the earth's rotation axis; that changes are always going on has been made clear by the discovery that the latitude of every place is continually varying. Some few years ago an International Congress decided that a systematic investigation should be made, and they suggested that the earth should be surrounded by a girdle of special observatories. The parallel of 39° north was selected for the girdle, with the result that three observatories fell in the United States, one in Japan, one in Russia, one in Sardinia. The Russian Government was asked in accordance with this scheme to erect an observatory at Tschardjui: Russia had been already for some years observing the variations of latitude at Pulkowa, at Moscow, at Warsaw and at Kazan, and the new observatory at Tschardjui made her fifth. India has so far not been asked to contribute to this work: she profits nevertheless from the results.

THE PENDULUM OPERATIONS.

The progress of foreign surveys.

The number of stations at which the pendulum had been observed prior to 1903, were*—

Great Britain	63
Italy	193
France	89
Austria	569
Germany	280
United States	108
Russia	153
India	29

Pendulum observations are now being taken by the surveys of France, Germany, Russia, Austria, Italy, Japan and the United States.

France has volunteered to undertake a gravimetric survey of the Andes: Germany has undertaken one of the oceans and coast-lines of the world; the United States and Russia have enormous areas of their own; and Great Britain sent a complete pendulum equipment to the Antarctic two years ago.

But, for pendulum research, the most interesting place on the earth is the mountainous region of Northern India, and the International Conference that met at Copenhagen in 1903 passed the following resolution on this subject for submission to the Government of India†:—

"Il est desirable qu'on fasse dans les Indes anglaises une étude approfondie de la répartition de la pesanteur, tant dans les contrées montagneuses que dans les plaines."

"Attendu que c'est seulment par cette étude qu'on pourra obtenir une representation exacte de la distribution des masses dans l'écorce terrestre et de la forme du géoide dans ces contrées."

The British Ambassador at Berlin submitted the above resolution to the Government of India on October 6th, 1903. Pendulum observations were commenced in India in 1904.‡

The purposes served by Pendulum observations.

Pendulum observations are of use—

(*1stly*).—For correcting and perfecting our astronomical checks on the triangulation.

(*2ndly*).—For determining the earth's ellipticity by a method independent of arc-measurements.

(*3rdly*).—For investigating the departures of the geoid from a Newtonian spheroid.

(*4thly*).—For investigating the constitution of the earth's crust.

The first purpose served by pendulum observations is, therefore, geographic, the second and third are astronomic, the fourth is geoiogic; all are geodetic.

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* Reports of the International Conferences at Paris in 1900 and at Copenhagen in 1903. Observations at 29 pendulum stations in India were made between 1866 and 1871: the work was stopped because the only apparatus procurable was too heavy and wearisome. Of the 63 stations appertaining to Great Britain but 16 fall in Great Britain itself: the remainder, though occupied by British observers, fall in Spitzbergen, South America and other places.

† See A proceedings No. 2, December 1903, Department of Revenue and Agriculture, Government of India.

‡ The Surveyor-General had obtained the sanction of Government to the purchase of a pendulum apparatus in 1902, and thus anticipated the wish of the International Conference.

We are profoundly ignorant of the constitution of the earth: we do not know if its interior is rock or metal, solid or molten: we talk of its crust, but we do not know if it has a crust distinct from its core: we do not know if the existence of high mountains is an incident of the earth's surface only, or if their superincumbent weight is producing inequalities of density at great depths. We do not know how these mountains have arisen. Pendulum operations have consequently a high value and interest for geologists and geodesists.

Geographical, astronomical and geological observations have all in their turn revealed peculiar physical features in the Himalayas, and we are now calling the pendulum to our aid to supplement our knowledge of Himalayan structure.

But when discussing the numerous uses of pendulum observations, we must not lose sight of the important fact that the pendulum is primarily a surveying instrument.

The connection between topography and pendulum work is, however, too complex to be described clearly in a single sentence, and must be traced step by step, as follows:—

(i) The geographical adjustment of the triangulation is dependent upon astronomical observations.

(ii) The correctness of astronomical observations depends upon the direction of gravity.

(iii) We cannot *measure* the direction of gravity, because we have no zero from which to measure. We can measure the *height* of a station, because the mean level of the sea is a reliable zero: we can measure *temperatures*, because the freezing point of water is a reliable zero: we can measure the deviation of the needle from true north. But we cannot measure the deviation of gravity from the true vertical, because the true vertical is not discoverable by observation as the true north is.

(iv) Owing to the deflections of gravity, astronomical measurements may cause an error of 800 or 1,000 feet in the geographical position of any point, and an error of a mile in the position of a Himalayan point.

(v) No deflections of gravity would occur on a perfectly level spheroid formed of homogeneous spheroidal layers: they are caused by the irregular distribution of masses at the earth's surface and in the earth's crust. The pendulum is required to demonstrate the true distribution of mass, and to show to us the extent to which our actual earth differs from a level spheroid composed of homogeneous layers.

(vi) If we know the mean density of the earth and the local distribution of mass at its surface, we can calculate the amount that gravity will be deflected from the normal. By providing us, therefore, with an ideal spheroid the pendulum supplies the zero which nature has failed to furnish.

The primary use, then, of pendulum work is that it enables the surveyors to correct their astronomical results for the unavoidable errors caused by deflections of gravity. The location of India on the globe has, for instance, rested upon astronomical observations made at a point in Central India. Everest selected this spot because there were no mountains visible, and because it seemed to be a place at which the direction of gravity would be truly vertical, and at which the instrumental levels would be truly horizontal. But only in the last few years we have discovered that Everest's point is situated on the scarp of a buried range or table-land; this range is deflecting gravity out of the normal, and must have disturbed the horizontality of Everest's levels; pendulum observations will disclose the mass and position of the hidden range, and will enable us to compute corrections for the astronomical results.

Thus it will be seen that pendulum observations are used to control astronomical results, just as astronomical observations are used to control the triangulation, and as the triangulation is used to control the topography: all are links in one chain.

THE TIDAL OPERATIONS.

Retrospect.

The investigations and writings of Professor George Darwin, have within the last thirty years, considerably increased our knowledge of the tides. Though we are still unable to foretell the course of the tides at places, where no observations have been taken, yet our predictions at ports at which the tides have been observed are now attaining an accuracy which would not have been credited half a century ago.

Tidal operations in India were initiated for the following purposes :—

(1) To provide a datum for the levelling operations of the survey.

(2) To afford data for the calculation of tidal predictions.

(3) To obtain evidence of the rising and sinking of land and of variations in mean sea-level.

Up to 1883, predictions of the tides were calculated by an arbitrary method which made no allowance for what is known as the diurnal inequality.*

In home waters the diurnal inequality is practically absent, and the European admiralties and surveys have never been really troubled by it. But in Indian waters it is very large, so large that in some of our ports at certain times there is only one tide in 24 hours. Owing to this phenomenon the earliest attempts at tidal prediction which were made in India for Karachi and Bombay were not successful ; and for many years all endeavours to foretell the tides at Aden failed. In 1883, Darwin revised the method of Harmonic Analysis as applied to the tides formulated by Sir William Thomson in 1872, and we are now able to unravel their extreme complication in Indian waters. The average error in the predicted height of high water at Aden is now one inch. If we reflect that the motions of the sun and moon, the complex outline of our coasts, the ever-varying depths of the sea, and the earth's rotation and figure are all involved, we cannot but regard modern tidal prediction as one of the greatest triumphs of science.

India was the first country to adopt this method of prediction : her success has been extraordinary, and her example has been slowly followed by Canada, the United States, by France and other European nations.

By means of Harmonic Analysis we can separate the observed tides into twenty-four components, and by means of Lord Kelvin's tide-predicting machine we can again combine these components and discover, mechanically, the actual tides of the future. For many years India was the only country that possessed a tide-predicting machine : but latterly France, the United States and Canada have had machines constructed. The tide-predicting machine of the Indian Government has been used in Europe for the tidal predictions of British colonies, and for this reason has never been sent to India. For many years it stood at Lambeth, but has lately been received at the National Physical Laboratory at Teddington.

The predictions of the Indian tides are carried out under the following quadruple arrangement :—

(i). The tidal observations are taken under the superintendence and orders of the local port officers and engineers.

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* This inequality is easily understood from a diagram.

(ii). The Survey of India has the duty of inspecting the several tidal observatories and of maintaining uniformity of method: the Survey of India has the further duties of reading off the tidal diagrams and of calculating by Harmonic Analysis the twenty-four tidal components.

(iii). The National Physical Laboratory in England sets the tidal machine to accord with the results of our calculations, and prepares the tidal predictions from the curves drawn by the machine.

(iv). From the beginning the operations have been under the scientific direction of Professor Darwin, whose advice has been constantly sought.

If tidal observations are taken for five years, sufficient data are accumulated to enable predictions to be made; the present predictions for some of the Indian ports are being still based upon observations taken more than twenty years ago and continue to be accurate. But lest in the course of years the tides may be slowly varying, or lest the relative heights of sea and land may be altering, a few observatories have been established on a permanent basis.

Between 1874 and 1904, tidal observations were taken at 42 places: of these observatories 34 were temporary and 8 permanent. At the present time one temporary observatory and the eight permanent are working.

Of our 42 tidal observatories two were in the Red Sea, two in Arabia, one in the Persian Gulf, one in the Maldives, three in Ceylon, one in the Andamans, twenty-four in India and eight in Burma.

Comparisons with foreign surveys.

The levelling results have been tested against tidal determinations of mean sea-level at 20 different places on the coasts of India.

In Great Britain, prior to 1861, the levelling results of the Ordnance Survey had been compared with tidal measurements of sea-level at 30 places in England and Wales, at 18 places in Scotland and at 21 places in Ireland.*

The following table shows the number of permanent tidal observatories working in 1902† :—

Country.	Length of Coast-line in miles.	No. of tidal Observatories.
Tonquin (France)	150	1
Austria	300	1
Holland	400	20
Denmark	500	10
Algiers (France)	600	1
Germany	800	26
New South Wales	800	3
France	1,300	11
Italy	1,600	16
Canada	2,000	7
Russia	2,000	10
Japan	2,600	10
New Zealand	3,000	6
Great Britain	3,000	9
India	4,000	8

* Abstracts of Spirit Levelling, Ordnance Survey, 1861.

† International Conferences, Stuttgart, 1898, and Copenhagen, 1903.

Future work.

The following tidal work will be carried out by the Survey of India in future :—

(i). Maintenance of eight permanent tidal observatories.

(ii). Annual calculations for the tide-predictions for 42 different ports.

(iii). Opening of new tidal observatories, of which two have been proposed for the Malay Peninsula, one for the Red Sea and two for the Gulf of Cutch.

Scientific Investigations.

Up to a few years ago it was generally held by geologists that the earth was a globe of molten matter enclosed by a thin crust. Lord Kelvin has, however, shown that such a globe would yield to tidal forces, and that the oceanic tides would then be imperceptible. The oceanic tides consist in a motion of the water relatively to the land, and their existence proves that the land does not yield with perfect freedom. From the fortnightly tide observed in Indian waters, Lord Kelvin and Professor Darwin have shown that the earth possesses a rigidity greater than that of solid glass, though not greater than that of solid steel.

In my previous note on Astronomical work I alluded to the variation of latitude: this phenomenon has been attributed to shiftings of the earth's axis of rotation, to movements of the earth's centre of gravity, and to variations in the position of the equatorial protuberance with reference to places fixed on the earth's surface: as the axis of rotation and the centre of gravity and the equatorial protuberance shift, the oceans become disturbed, and a tide becomes generated. We are endeavouring now, under the direction of Professor Darwin, to detect a tide at Karachi corresponding in its period of 430 days with the variation of latitude: the United States Geodetic Survey have discovered such a tide on their coasts, and the Geodetic Survey of Holland has also detected it. This tide is of course minute, as the movements of the earth's axis are small: if the displacements of the axis were considerable, whole continents would be drowned by gigantic waves.*

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* Darwin's Tides: p. 230

THE MAGNETIC SURVEY AND SOLAR PHOTOGRAPHY.

A Magnetic Survey of India was proposed in 1896 by Sir John Eliot and General Strahan, and was recommended by the Astronomers who visited India in 1898, on the occasion of the total eclipse of the sun.* At the outset there was some uncertainty as to whether the work should be undertaken by the Survey of India or by the Meteorological Department, and it was eventually decided that the field-work should be carried out under the Surveyor-General, and that the fixed observatories should be under the Meteorological Reporter. By mutual agreement, however, the Meteorological Reporter has now handed over the charge of four of the five observatories to the Surveyor-General. The Magnetic Survey of India was begun in 1900.

Many branches of science are interested in a Magnetic Survey: the meteorologists require it to assist them in their investigation of the connection between sunspots and rainfall: the geologists expect it to show them the positions of magnetic rocks: geographers and navigators derive from it their knowledge of the declination of the compass, and the secular changes in the declination.

The existence of magnetic rocks in the crust can at times be detected by ordinary compasses, but if iron ore is lying concealed at any great depth from the surface, its presence would be only discovered by a systematic and rigorous survey.

Though the magnetic surveys of Europe and America have greatly progressed of recent years, but a small fraction of the surface of the globe has as yet been examined. We do not at present know whether the earth's magnetism is due to permanent centres of attraction or to its rotatary motion: we do not know whether the earth is a permanent magnet or not.

Dates of Magnetic discoveries.

1492. Discovery that a needle does not point true north, and that its declination differs in different parts of the earth.

1576. Discovery that the north end of a needle if properly balanced will dip below the horizon, and that the amount of dip differs in different parts of the earth.

1634. Discovery that the magnetic declination constantly undergoes slow changes in the course of years, and that the rate of its change differs in different countries.

1720. Discovery that the strength or intensity of the earth's magnetic force differs in different countries, and at different times.

1722. Discovery that the magnetic declination is subject to an appreciable diurnal tide, and that the range of this tide differs in different countries and at different seasons.

19th century. General Sabine shows that the earth's magnetism is not only a telluric but a cosmical force.

The Indian Magnetic Survey.

The immediate aim of a modern Magnetic Survey is to determine the declination, the dip and the intensity of the earth's magnetic force in every portion of the area involved, and to measure the several changes that these elements undergo.

* See Reports by Sir W. Christie, K.C.B., F.R.S. and Sir Norman Lockyer, K.C.B., F.R.S.

In the Magnetic Survey of India five field parties have been observing the declination, dip and intensity, in different parts of India since 1900; annual observations have also been taken at 17 "Repeat" stations to test the annual local variations in the elements; and continuous photographic records have been obtained at five observatories of the direction and intensity of the magnetic force.

The preliminary Magnetic Survey of India will be completed in 1906. Charts will then be prepared to show the localities where magnetic disturbances exist, and a detailed Magnetic Survey of those localities will be commenced under the guidance of the Royal Society.

In projecting the detailed survey, the Survey of India, conscious of a heavy responsibility, will rely upon the co-operation of the Meteorological Reporter and of the Director of the Geological Survey.

We have been much indebted to Sir Arthur Rücker, K.C.B., F.R.S., for his interest, advice and instructions, and we count with confidence upon the continued sympathy of this eminent physicist.

Comparison of the Magnetic Surveys of Great Britain and of India.

The first complete Magnetic Survey was that of Great Britain in 1837-38. The example set by Great Britain was followed by Austria, Germany, Holland, France, Canada, Russia, Italy and the United States.

In 1857-62, after the lapse of twenty years, Great Britain repeated its original Magnetic Survey in order to investigate the changes that had occurred.

Between 1884 and 1888 Great Britain carried out a third Magnetic Survey, and between 1889 and 1892 it amplified this survey and made it the most detailed of the world.

Our present Magnetic Survey is the first attempted in India, but magnetic observations have been taken since 1846 at the Observatory in Colába, which was established by the East India Company, and this continuous series is undoubtedly a very valuable record.

The following Magnetic Observatories are now working:—

In Great Britain—	In India—
Greenwich.	Colába.
Kew.	Kŏdaikanál.
Stonyhurst.	Dehra Dún.
Valentia.	Barrackpore.
Falmouth.	Toungoo.

In Great Britain there were 26 "Repeat" stations, that is one "Repeat" station on the average to every 4,700 square miles.

In India there are projected 24 "Repeat" stations, or one "Repeat" station on the average to every 73,000 square miles.

In Great Britain there were 882 field stations, or one field station on the average to every 139 square miles.

In India there are projected 1,200 field stations, or one field station on the average to every 1,500 square miles.

I am not making these comparisons to illustrate the inferiority of the Indian Survey to the British, but to show that the Magnetic Survey of India has been designed with a proper regard for economy, and that no undue multiplicity of observations is being contemplated.

It is possible that when the detailed Magnetic Survey is being undertaken, we shall be pressed to multiply field stations in regions of magnetic disturbance.

The following information is extracted from the last report of the United States Survey, dated Washington, 1904:—

"Observations have been made at 1,636 stations, of which about one-eighth are 'Repeat' "stations: the average distance between the stations is 25 miles,* although in regions of "pronounced disturbances the distances are much less: the area covered is one-third of the area "of the United States."

"Observatory work has been carried on at five stations."

"It is hoped that the next five years may witness greater progress."

Solar Photography.

Photographs of the Sun have been taken twice daily, clouds permitting, at Dehra Dún since 1879. Similar photographs have been also taken daily at Greenwich Observatory and at Mauritius. For many years Greenwich, Dehra Dún and Mauritius have acted together under one scheme and on one system. We send our photographs to England weekly to Sir Norman Lockyer, K.C.B., F.R.S., under whose directions we have carried out the work from its inception. In 1898 Sir William Christie, the Astronomer Royal, wrote to the Secretary of State: "The daily photographs of the Sun should be continued at Dehra Dún, where they are being taken satisfactorily under the Surveyor-General's direction†."

* Average distance in India 39 miles.

† Report on Indian Observatories.

G. I. C. P. O.—No. 911 S.-G.—15-3-06.—500.—R. H. S.